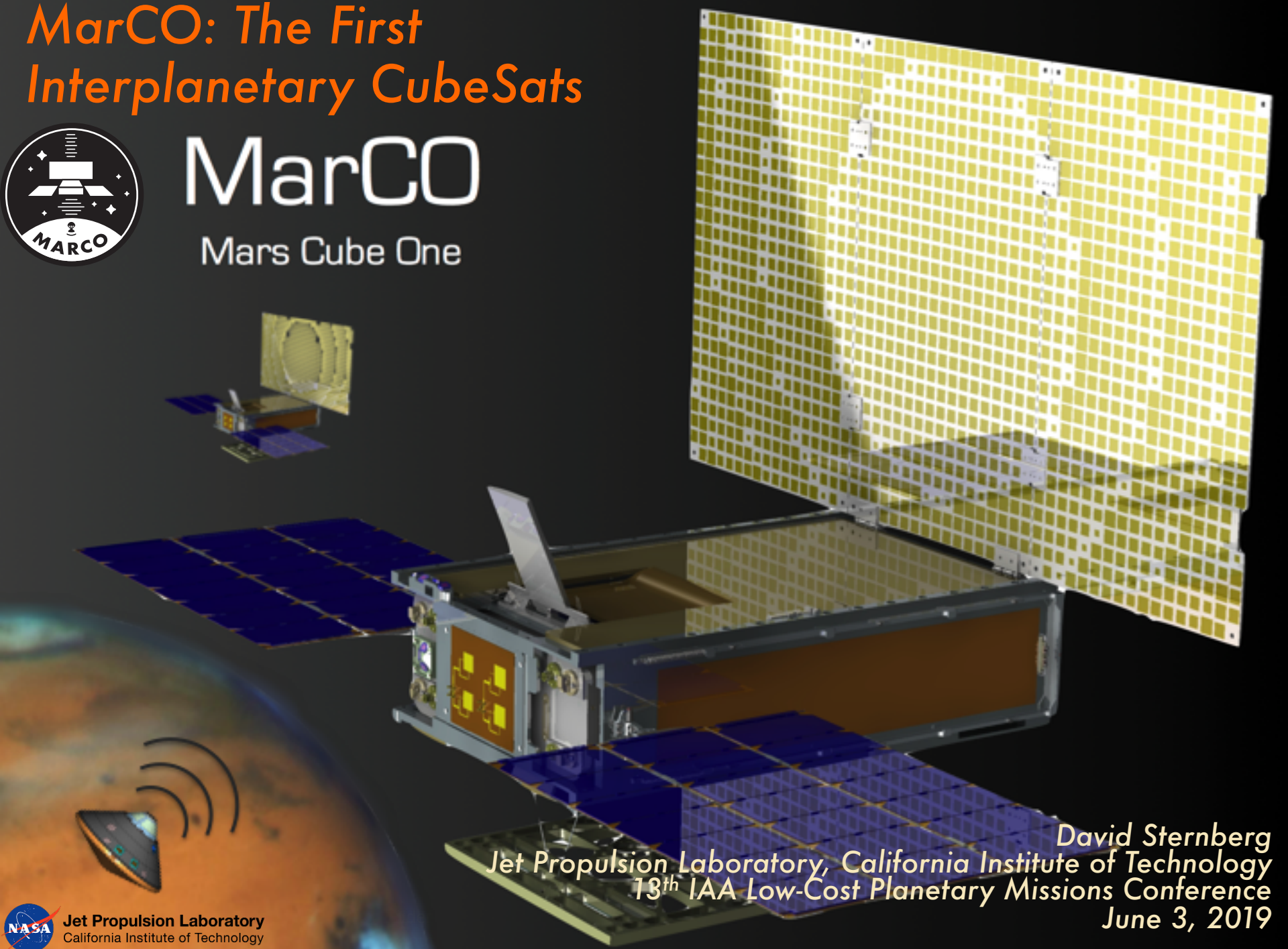
MarCO: The First Interplanetary CubeSats

MarCO

Mars Cube One



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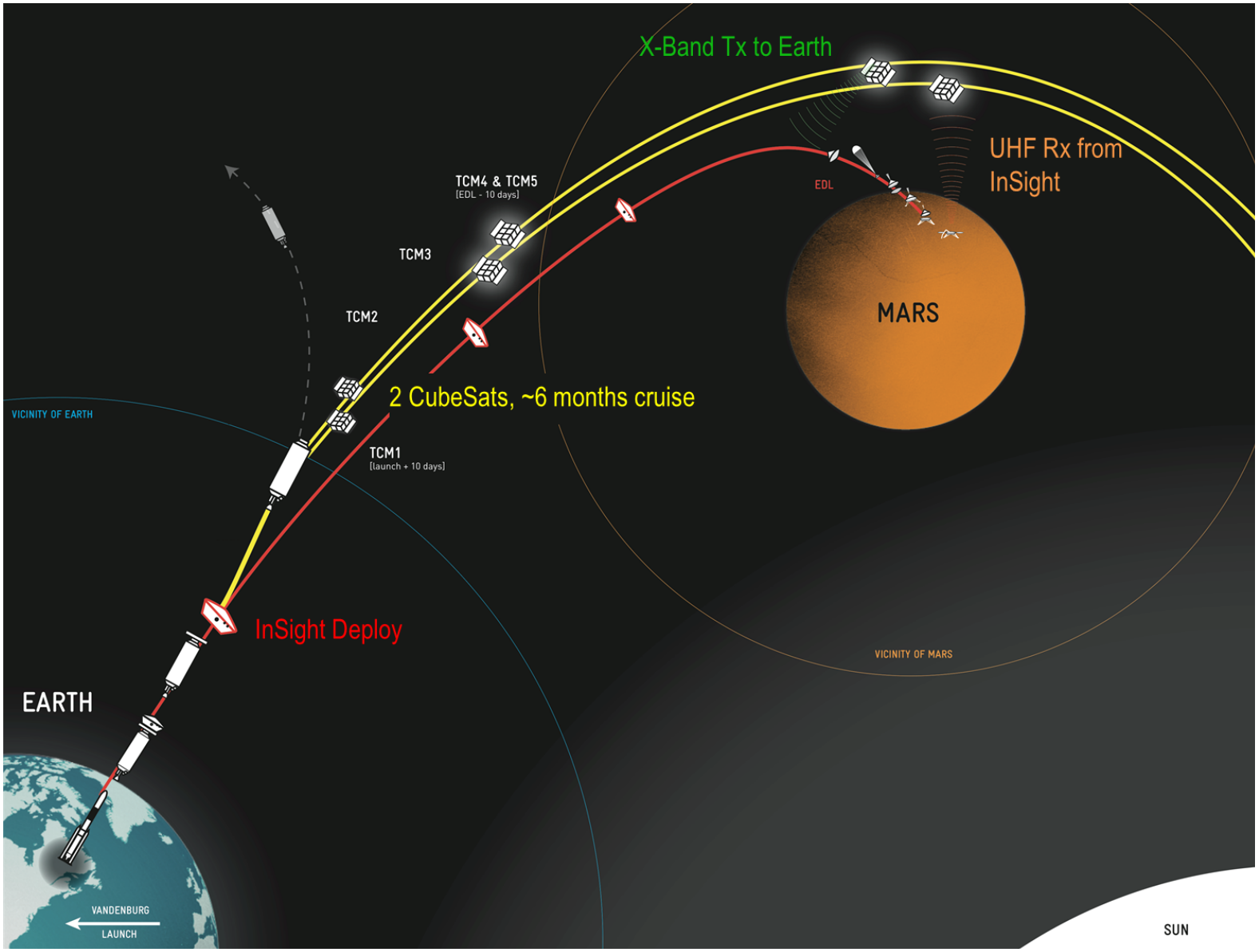
13th IAA Low-Cost Planetary Missions Conference
June 3, 2019

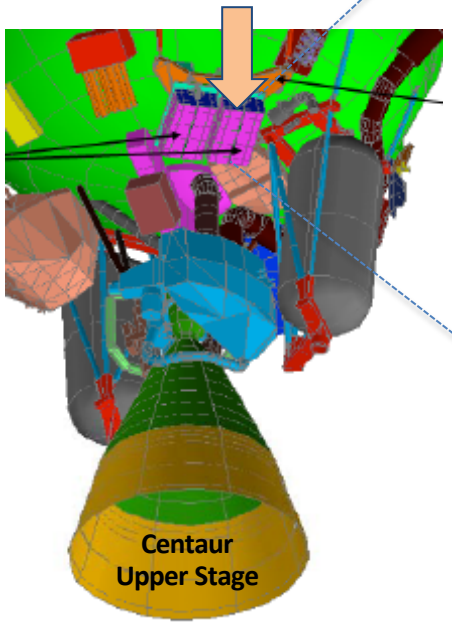
Jet Propulsion Laboratory
California Institute of Technology

MarCO Mission Summary



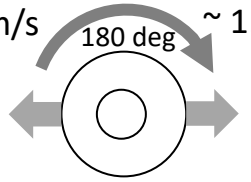
MarCO Mission Summary

1) Deploy MarCO-A & -B from Tyvak Dispensers (Twins for redundancy)



MarCO-A
~ 1.5 m/s

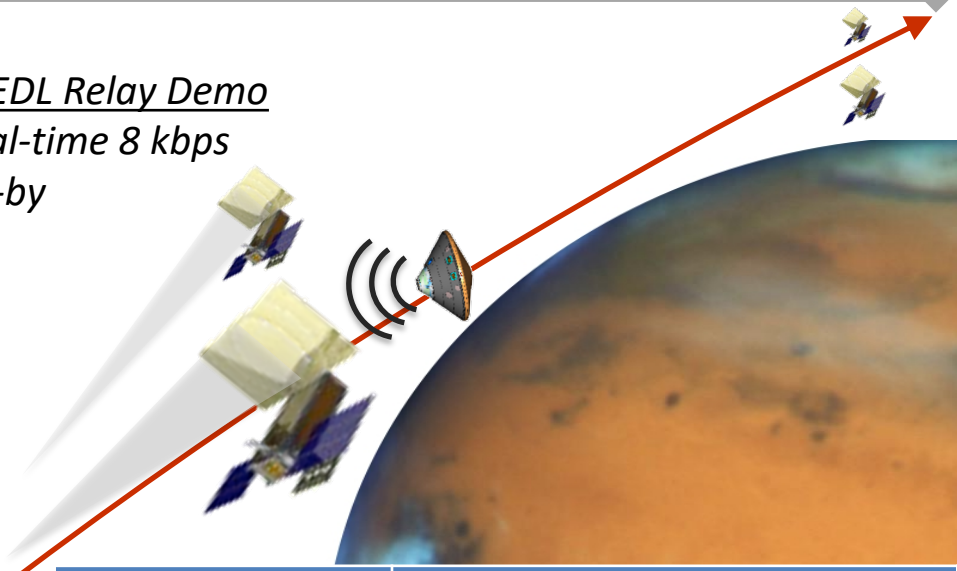
MarCO-B
~ 1.5 m/s



Earth

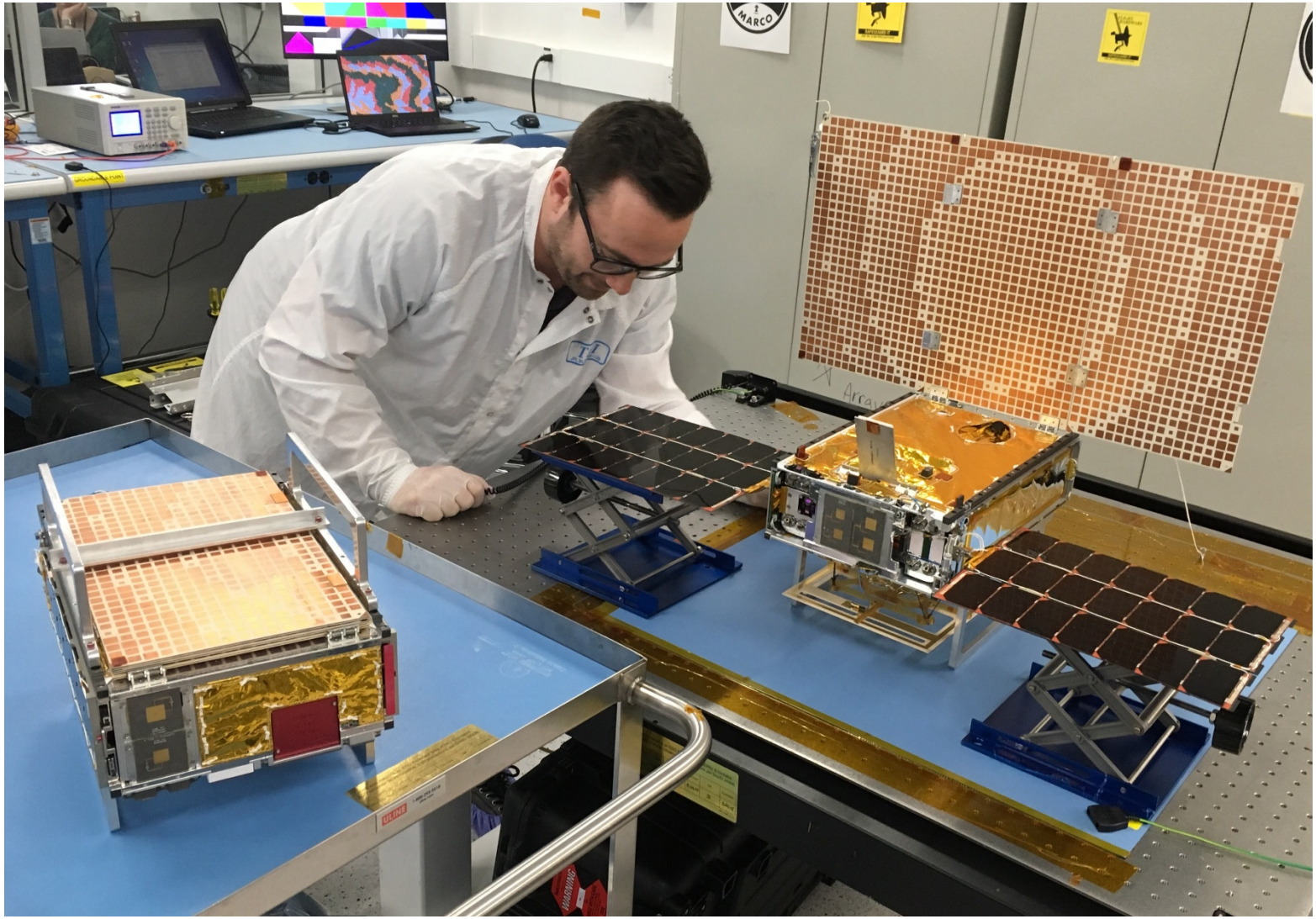
2) Early Cruise Tech Demo Of Telecom and TCM Technologies

3) EDL Relay Demo Real-time 8 kbps Fly-by

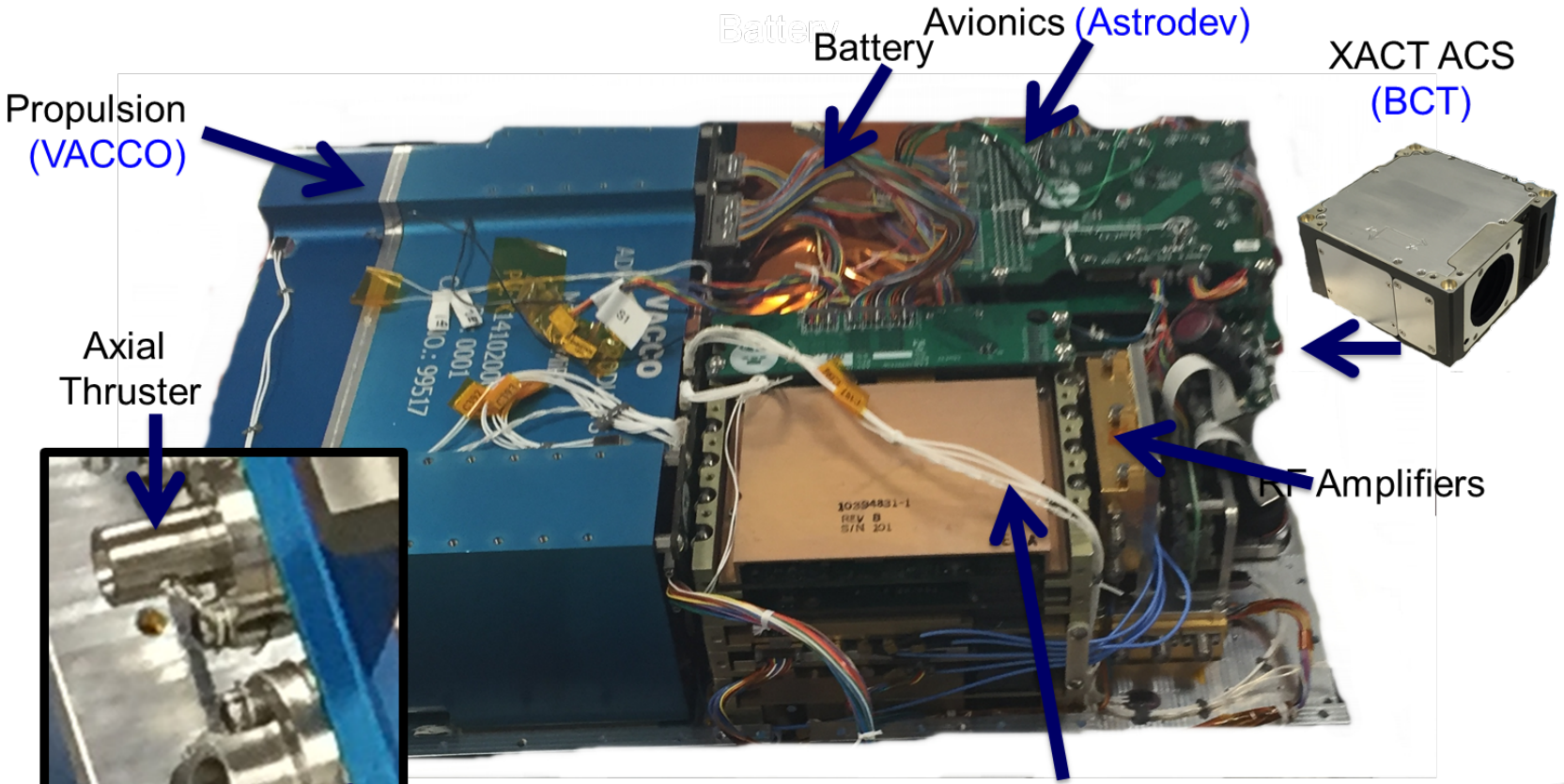


Technology	Mission Objectives
Threshold	
Miniaturized deep space radio (IRIS)	Successful uplink and downlink at multiple data rates + ranging
Flat Panel Antenna	Receipt of telemetry at 8kbps
TCMs on a CubeSat	Execution of TCM 1
Baseline	
CubeSat in deep space	Viable operations beyond Earth orbit
Relay	Bent-pipe during Insight EDL

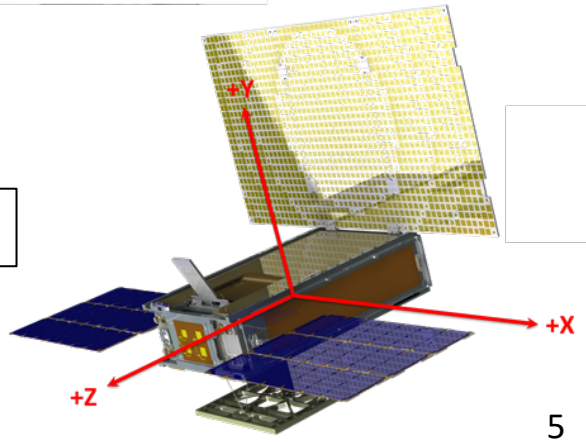
MarCO Spacecraft



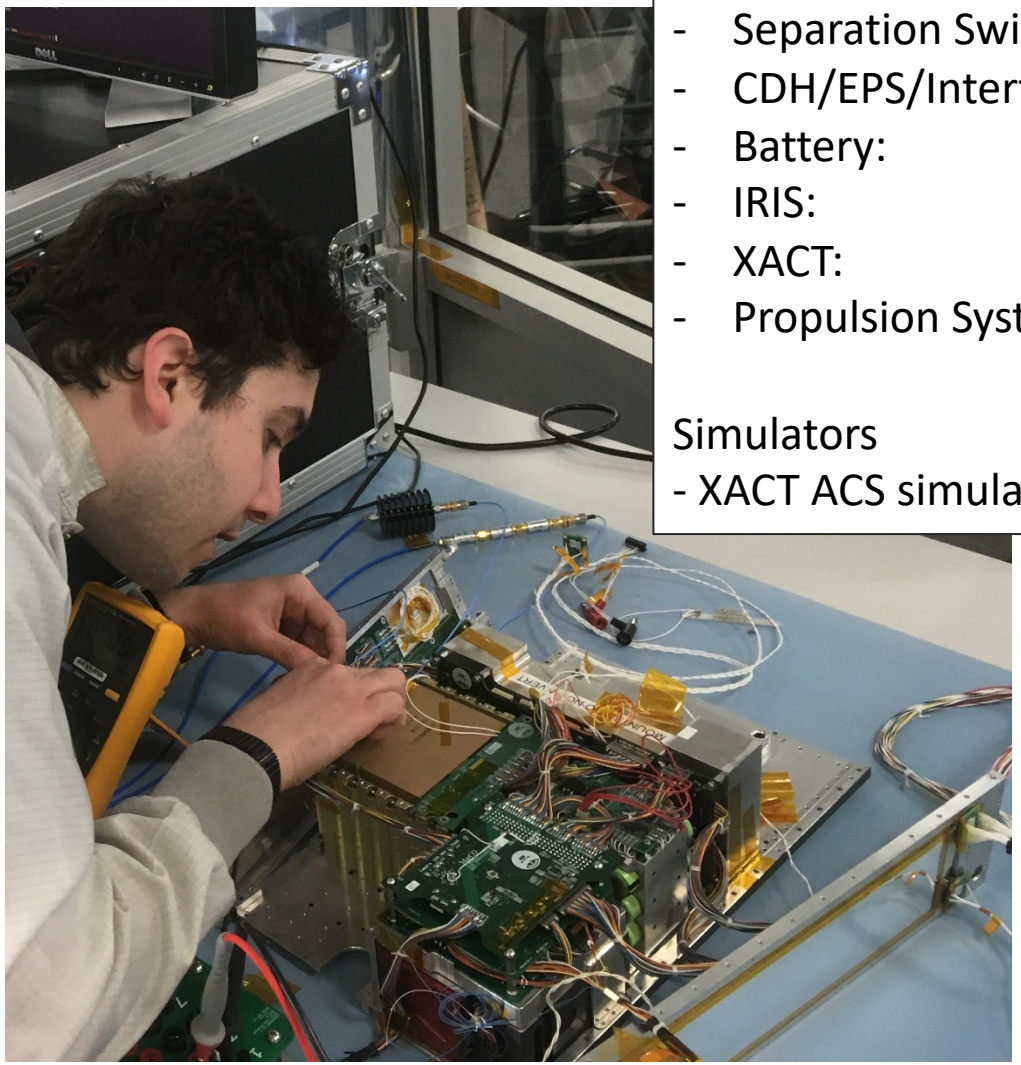
MarCO Internal Components Overview



Not shown: two coarse sun sensors



MarCO Ground Testbed

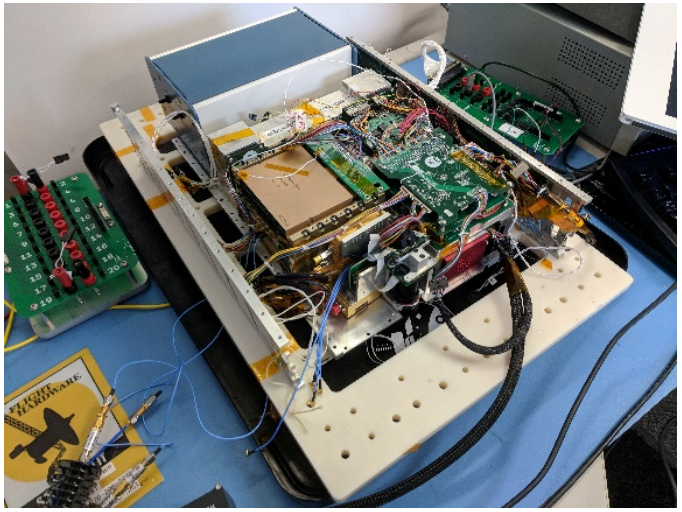


Comparison to FM:

- Separation Switch circuit	like FM
- CDH/EPS/Interface Boards:	like FM
- Battery:	like FM
- IRIS:	like FM1
- XACT:	like FM, but 1 CSS
- Propulsion System	electronics only

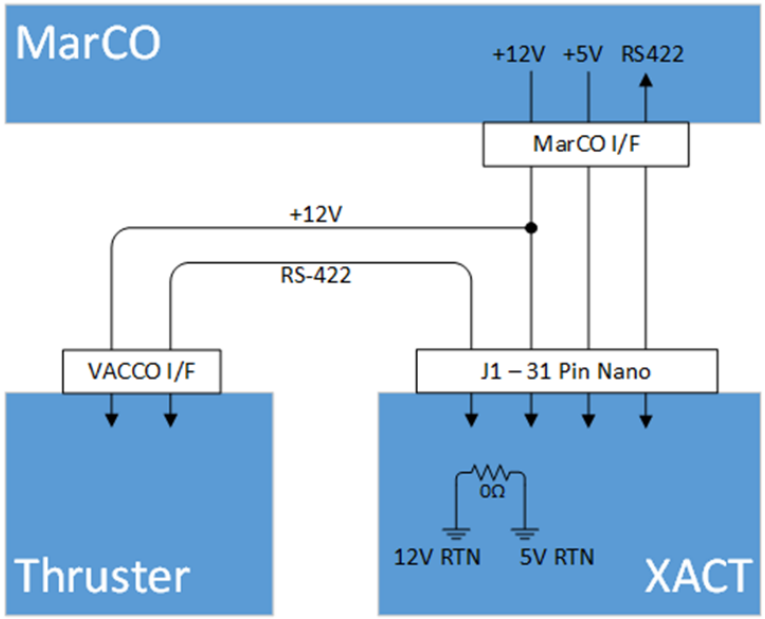
Simulators

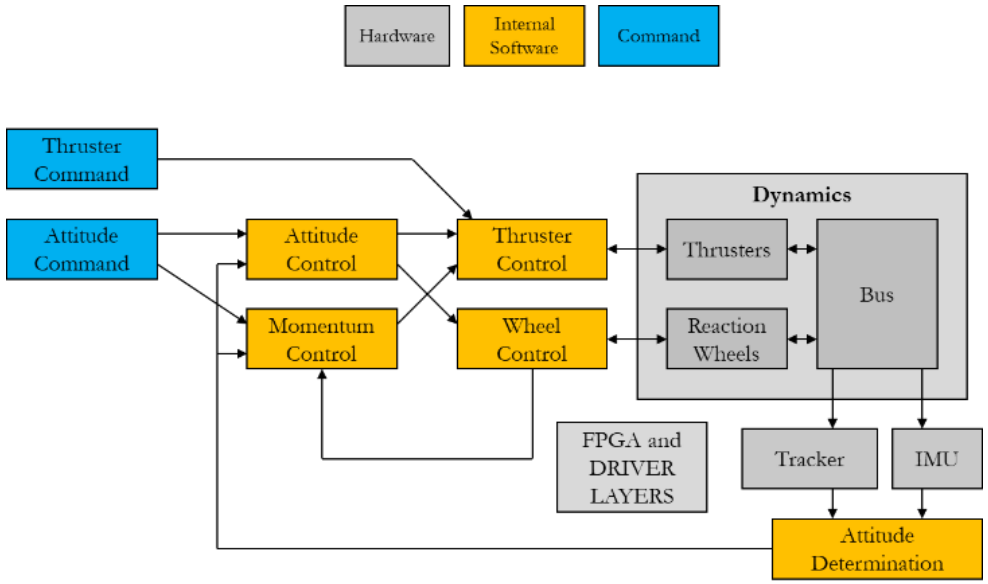
- XACT ACS simulator- Realtime Dynamics Processor (“RDP”)



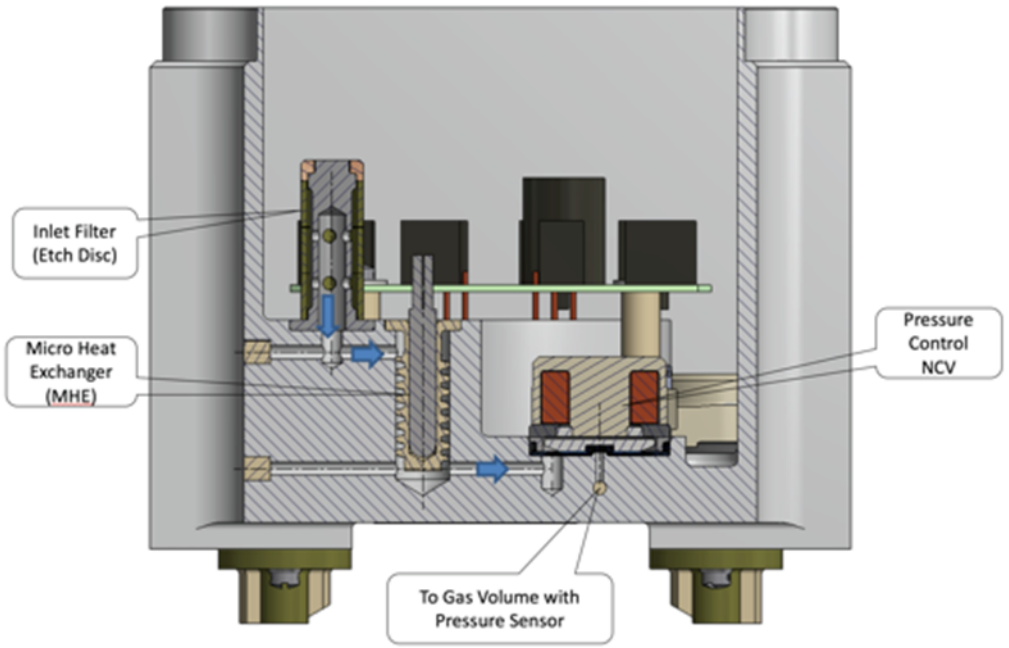
ACS/Prop Interface and Interaction

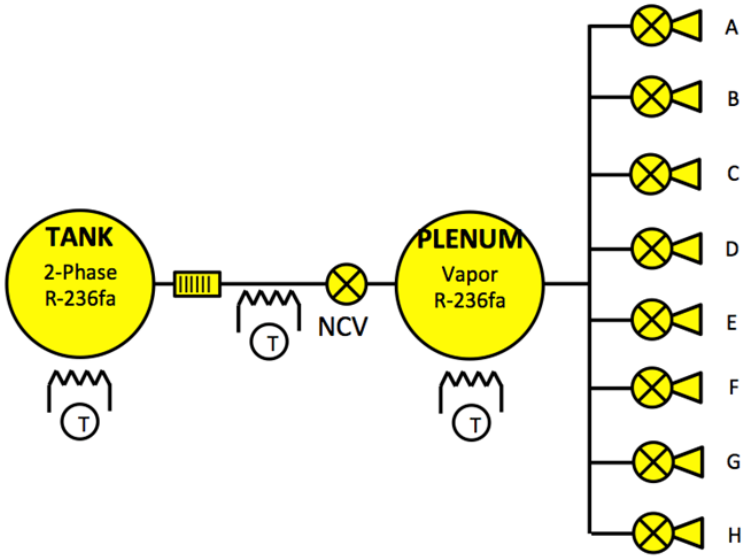
- All commands to propulsion system pass through the XACT
  - Ground commands for XACT's autonomous management of thrusters or for direct thruster actuation
  - Onboard ACS Manager (ACSM) prevents multiple ACS commands from being sent at once and reduces complexity of larger command sequences by acting on flag toggling





Propulsion System Overview





Delta V Budget [m/s]

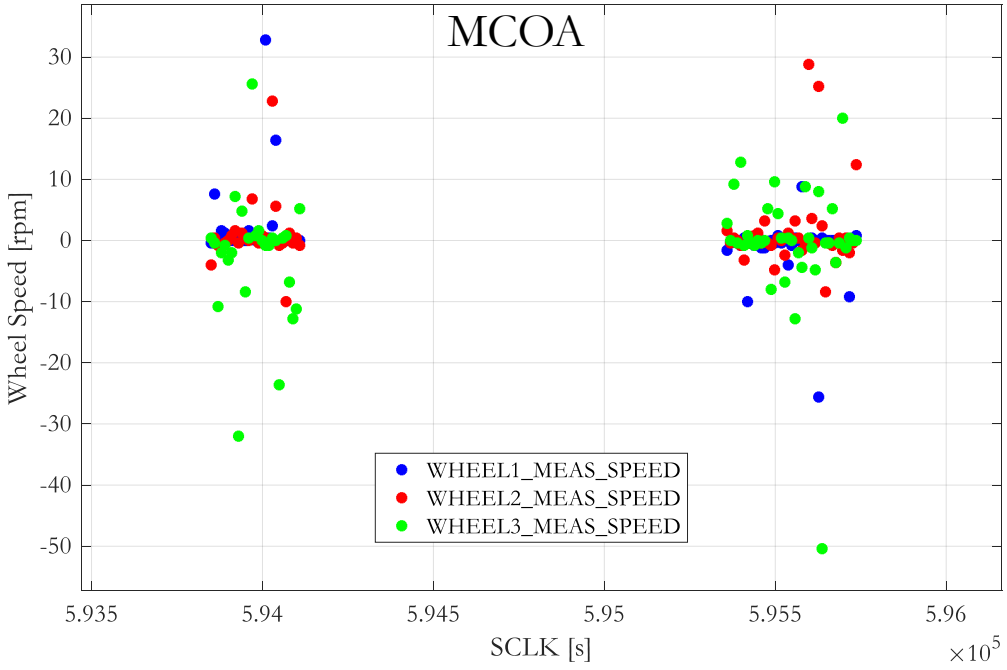
	TCM1	TCM2	TCM3	TCM4	TCM5	Total
Worst-Case Estimate	22.70	8.40	2.40	0.42	0.11	
					Sum	34.03
					Systems Margin	5.97
					Total Capacity	40.00

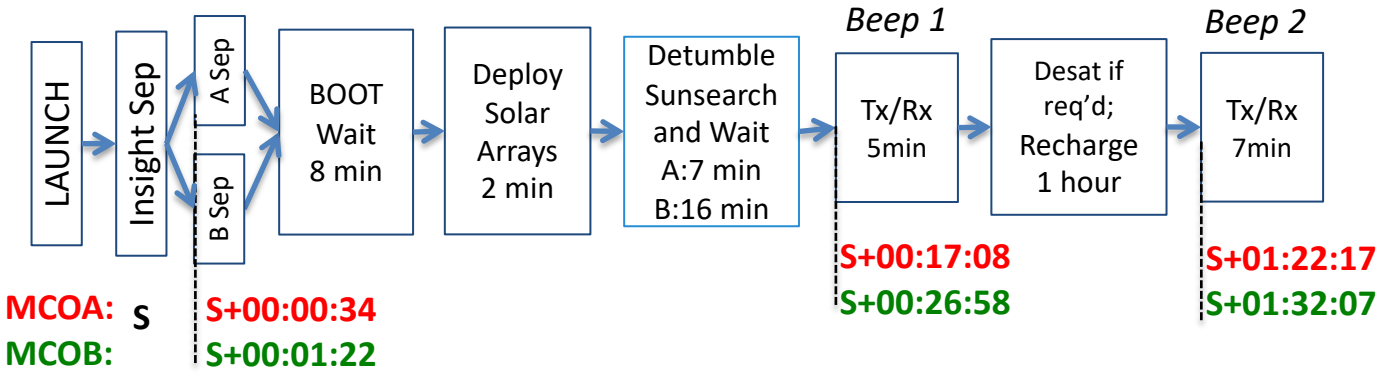
Propellant Mass Budget

Disturbance Torques	Propellant Mass [g]
Momentum Management	150
Detumbling	50
Reaction Control Margin	100
Reaction Control Total	300
Delta-V Propellant Need	1200
Delta-V Margin	370
Unusable Propellant	30
Total Propellant	1900

Flight Data: First Telemetry

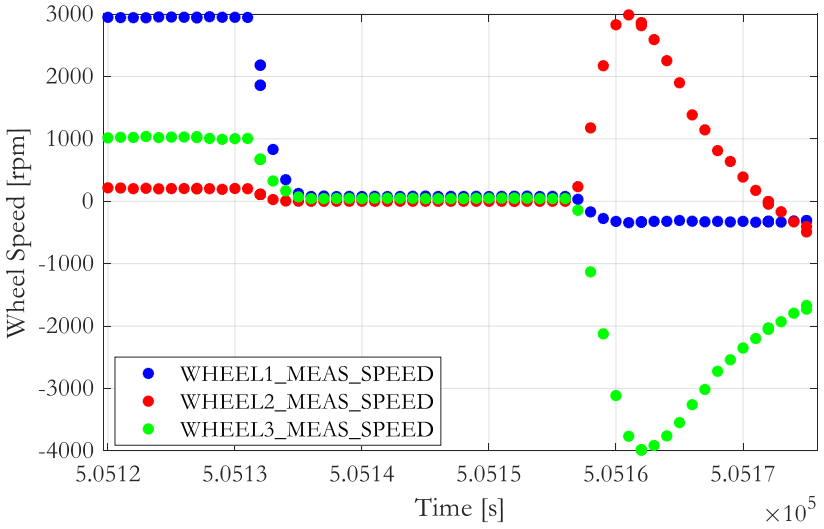
- First contact with the spacecraft was a pair of “beeps”
- Receive only (no commands sent) for five and seven minutes, respectively
- Each beep contained key telemetry to assess health of spacecraft
- Reaction wheel speeds indicate momentum stored after the desaturation if it was necessary and overall spacecraft attitude stability

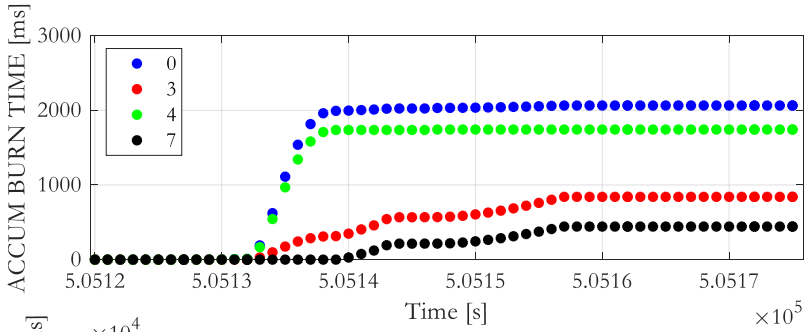


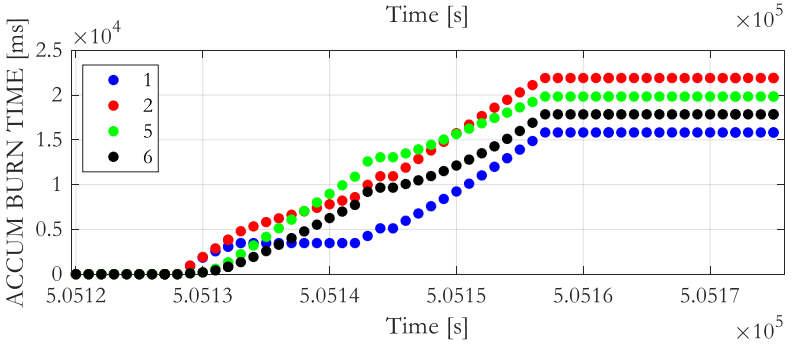


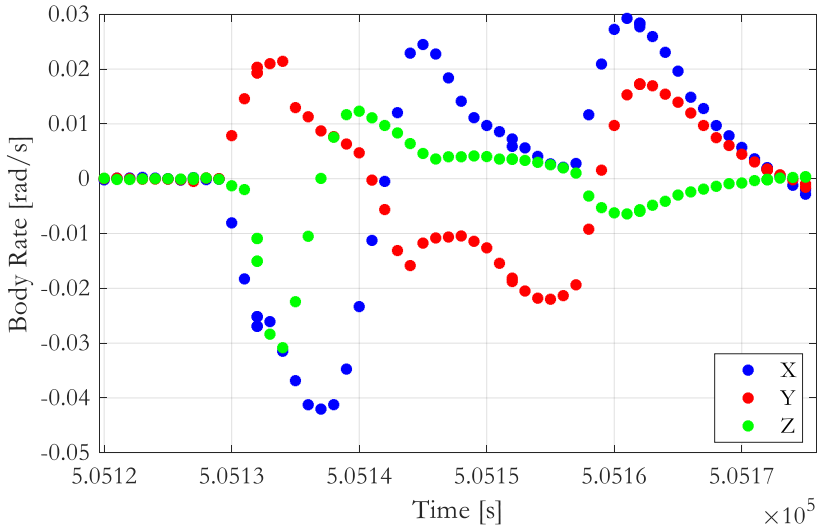
Flight Data: MCOA TCM2 Cleanup Maneuver

- TCMs performed in segments, with cleanup maneuvers for fine-tuning
- Off-pulsing thrusters is required for maintaining desired thrust direction
- Thruster controller is non-adaptive, so commanded thrust direction accounts for uncertainty in thrust levels and mass properties
- Spacecraft exhibits characteristic “nod” at start of burn, eventually corrected by reaction wheels at end of firing

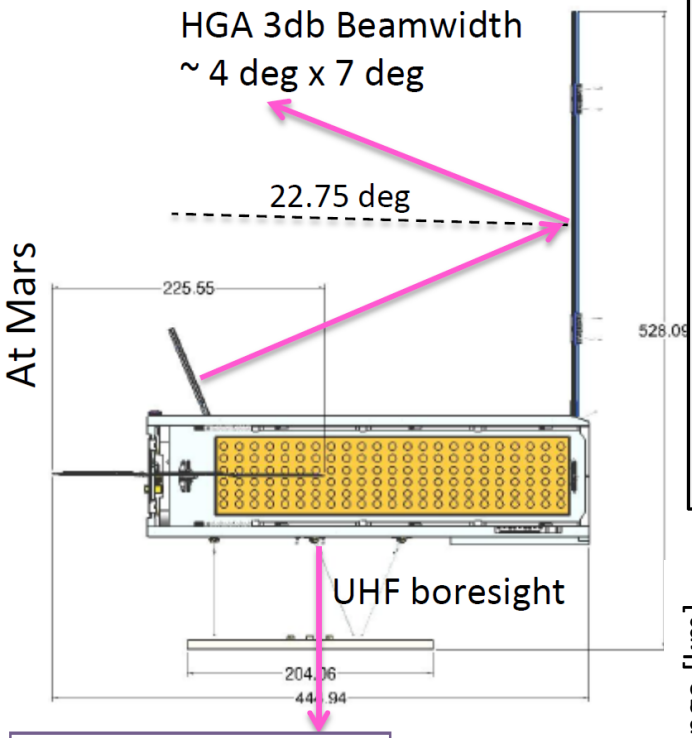




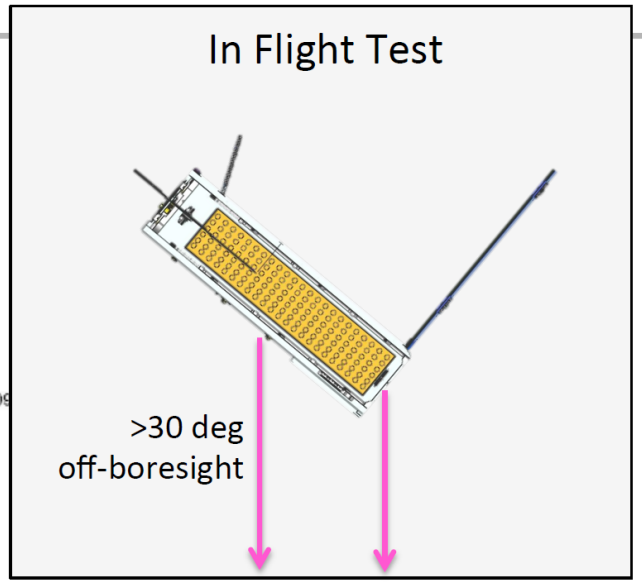


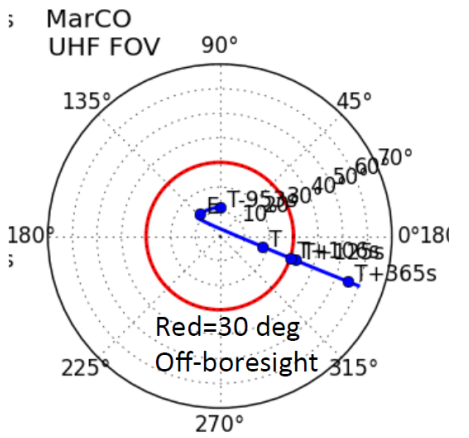


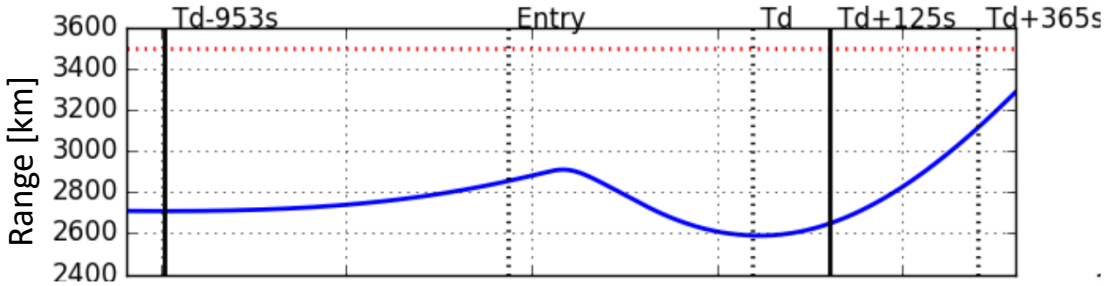
Bent Pipe Attitude

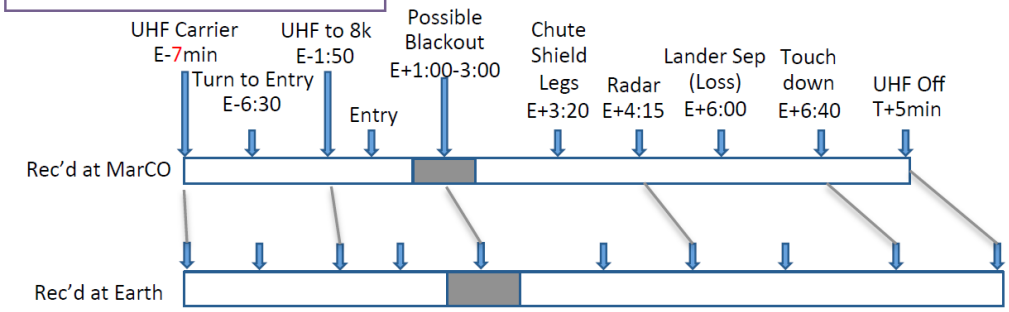


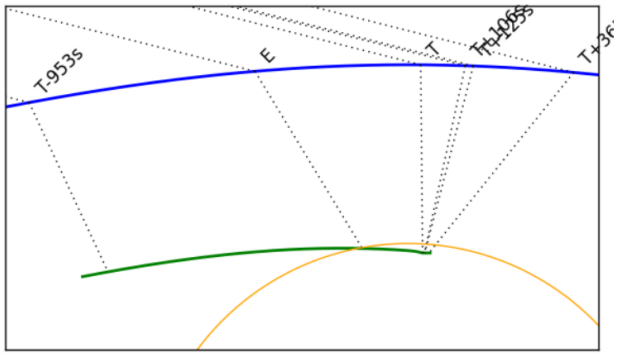
~15% "Overhead" on Bent Pipe:
MarCO Frame headers
+ Interleaved MarCO Data









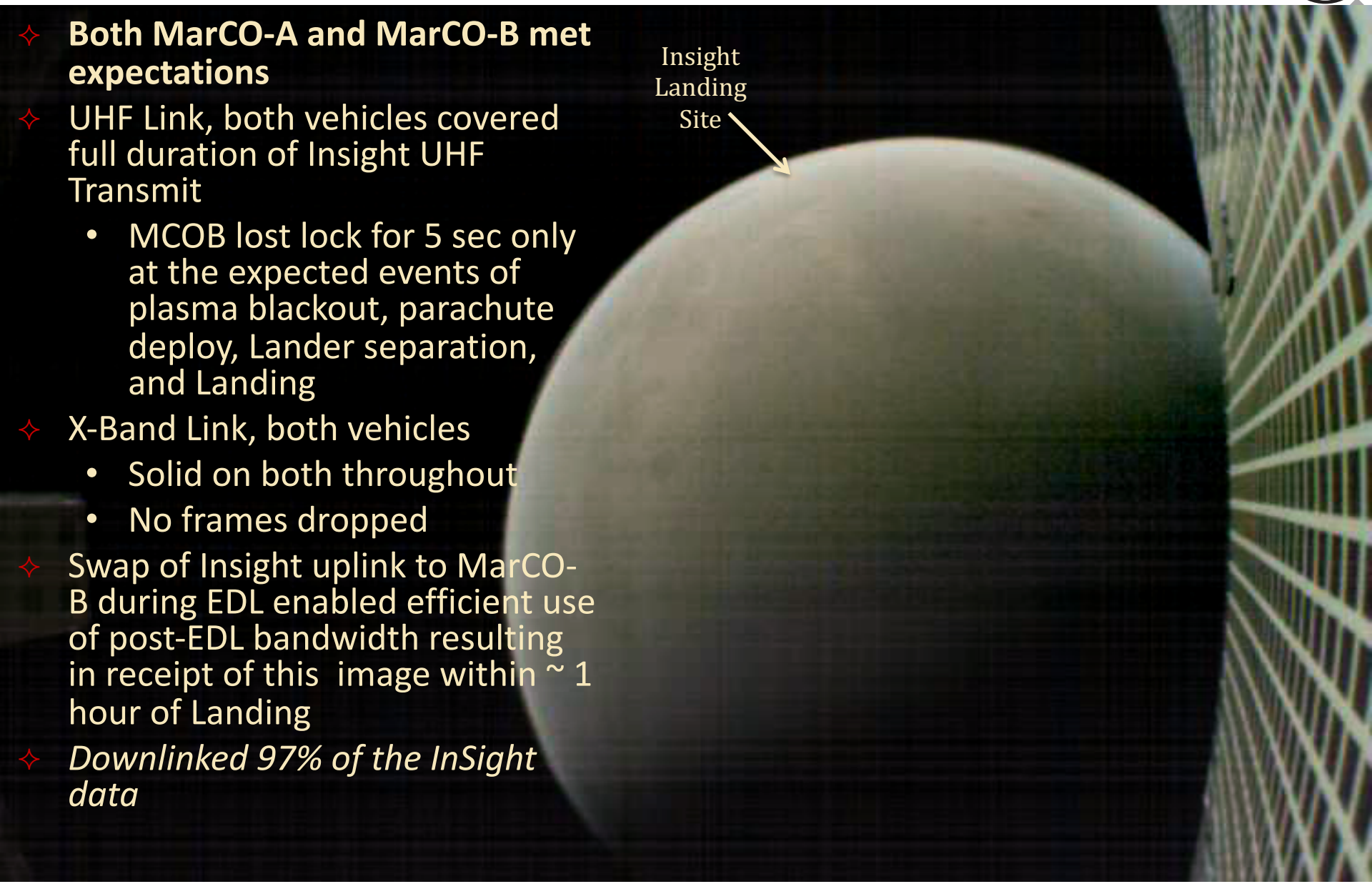


MarCO-InSight Relay

- Prioritization scheme based on packet type (APID)
  - InSight data would stream at a near continuous sense
  - 30 sec interrupts with a snapshot of MarCO health data and a 2 sec cadence history of relevant RF information
  - Anything not relevant for informing InSight about signal status was saved for later downlink.
- Could have maintained the 62.5 bps downlink to 70m DSN station using the MGA if HGA did not perform as expected
- Leveraged an optimized trajectory for relay performance - an advantage of the dedicated relay
- Able to rely on commercial equipment since only need to support the relay once (not staying in orbit)
- Add redundancy in sending two spacecraft (uncertainty in both MarCO performance and final InSight EDL trajectory)

MarCO Bent Pipe Performance for Insight EDL

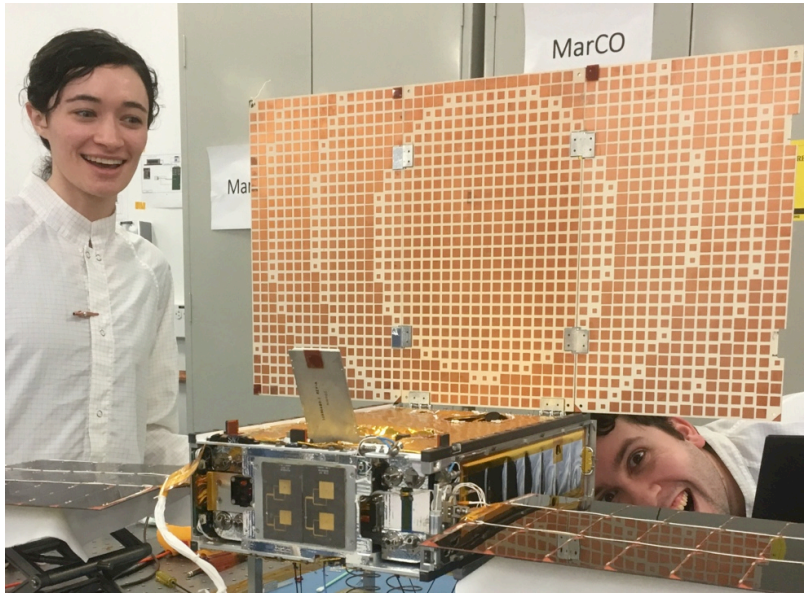
- **Both MarCO-A and MarCO-B met expectations**
- UHF Link, both vehicles covered full duration of Insight UHF Transmit
  - MCOB lost lock for 5 sec only at the expected events of plasma blackout, parachute deploy, Lander separation, and Landing
- X-Band Link, both vehicles
  - Solid on both throughout
  - No frames dropped
- Swap of Insight uplink to MarCO-B during EDL enabled efficient use of post-EDL bandwidth resulting in receipt of this image within ~ 1 hour of Landing
- *Downlinked 97% of the InSight data*



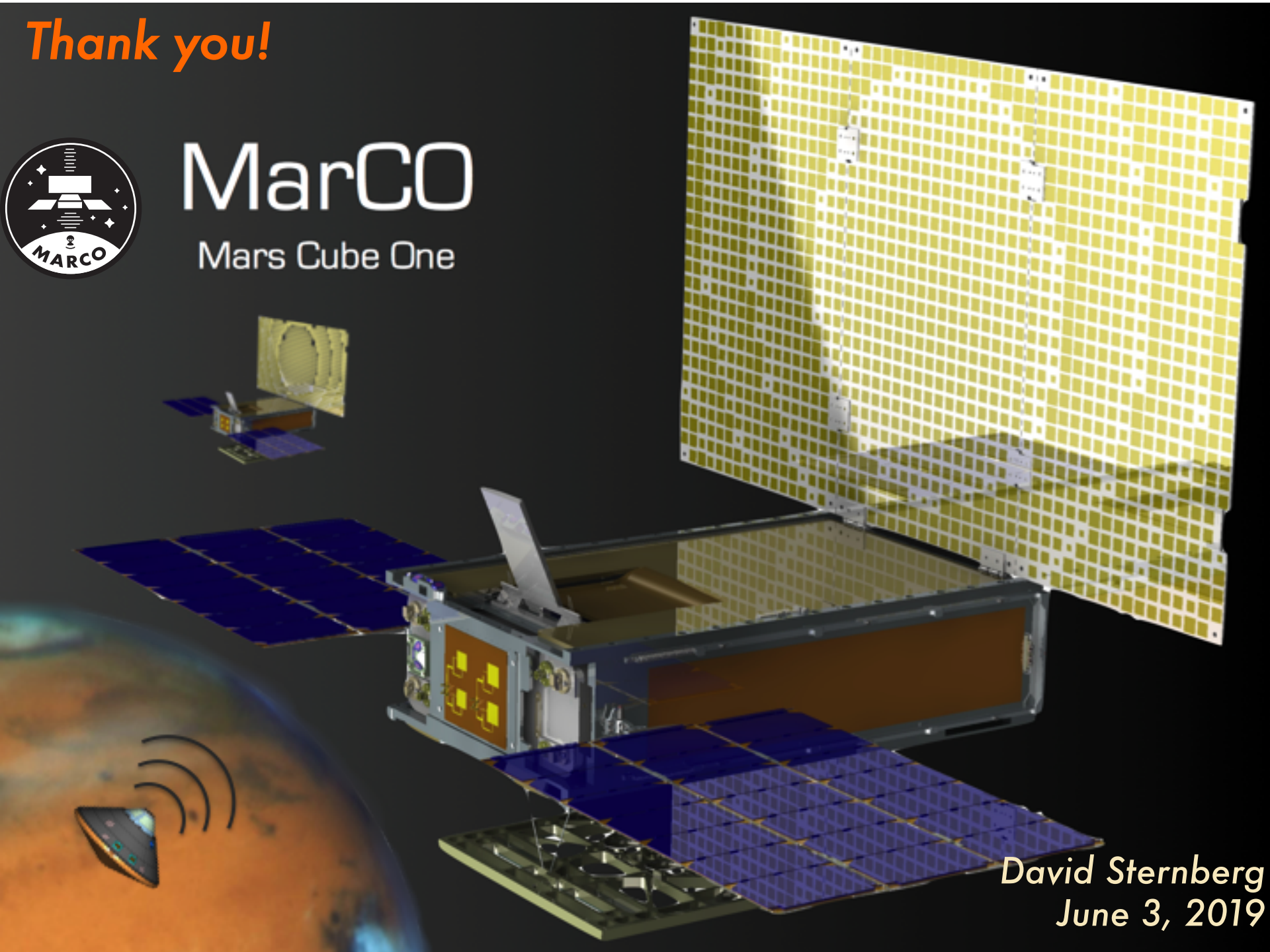
MarCO-B Wide FOV Camera Image, 26 November 2018; DOY330T20:10:00, ~ 6000km range

Conclusions

- Consider in the future:
  - Dedicated small spacecraft can support critical events when too costly or infeasible for others to perform the relay
  - Small spacecraft can be sent in multiples to provide improved coverage or signal reliability
- Lesson Learned:
  - Single uplink frequency for both
  - Had end to end simulation for both X band and UHF
  - In-space test with SRI (46m), Morehead was 21m



Thank you!



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June 3, 2019